

INTERNAL COMBUSTION ENGINE WITH A FUEL CELL IN AN EXHAUST SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an internal combustion engine with a fuel cell in an exhaust system.

2. Description of the Related Art

There has hitherto been known a technology in which a fuel cell is arranged in an exhaust system of an internal combustion engine so that unburnt components of fuel discharged from the internal combustion engine, which is caused to operate in a state of excessive fuel, are supplied, as fuel for electric power generation, to a fuel electrode side of the fuel cell (for example, see a first patent document: Japanese patent application laid-open No. 2002-175824 (pages 4-7 and Fig. 1)).

However, it might sometimes be difficult to operate the internal combustion engine in the state of excessive fuel depending upon the operating condition of the internal combustion engine, and in this case, fuel cannot be supplied to the fuel cell. In addition, in such a case, when power generation of the fuel cell is given priority so as to cause the internal combustion engine to operate in the state of excessive fuel, the operating state of the internal combustion engine is deteriorated, thus giving rise to a fear that torque fluctuation and/or deterioration of emissions might be induced.

SUMMARY OF THE INVENTION

Accordingly, the present invention has been made in view of the problems as referred to above, and has for its object to provide a technology in which in an internal combustion engine with a fuel cell in an exhaust system, fuel for power generation is able to be supplied to the fuel cell without regard to the operating condition of the internal combustion engine.

In order to achieve the above object, according to one aspect of the present invention, there is provided an internal combustion engine with a fuel cell in an exhaust system, the engine comprising: a fuel cell having a fuel

electrode side thereof connected with an exhaust passage of the internal combustion engine; a fuel supply system that supplies power generation fuel for the fuel cell to an exhaust passage at a location downstream of the internal combustion engine and upstream of the fuel cell; and a supply amount control part that controls an amount of power generation fuel supplied by the fuel supply system.

The major feature of the present invention is that by the provision of the fuel supply system that supplies the power generation fuel to an intermediate portion of the exhaust passage, the power generation fuel can be supplied to the fuel cell without regard to the operating condition of the internal combustion engine.

In the internal combustion engine with the fuel cell in the exhaust system as constructed in this manner, by the provision of the fuel supply system, the power generation fuel can be supplied to a fuel electrode side of the fuel cell without regard to the operating condition of the internal combustion engine. In addition, since the amount of supply of the power generation fuel is controlled by the supply amount control part, an appropriate amount of power generation fuel can be supplied to the fuel cell without regard to the operating condition of the internal combustion engine. On the other hand, the internal combustion engine can be caused to operate without regard to the state of power generation in the fuel cell, whereby torque fluctuation and the deterioration of emissions due to the deterioration of the operating state of the internal combustion engine can be suppressed.

Preferably, the supply amount control part may control the amount of power generation fuel supplied by the fuel supply system in such a manner that an amount of electric power generation of the fuel cell becomes equal to a target amount of electric power generation. With this arrangement, it is possible to supply the power generation fuel to the fuel cell without regard to the operating condition of the internal combustion engine, as a result of which the amount of supply of the power generation fuel can be controlled based on the target amount of electric power generation of the fuel cell. Thus, an optimal amount of power generation fuel can be supplied to the fuel cell so as

to achieve the target amount of electric power generation thereof.

Preferably, the internal combustion engine may further comprise a fuel amount detection device that detects an amount of power generation fuel contributing to the power generation of the fuel cell, wherein the supply amount control part controls the amount of power generation fuel supplied by the fuel supply system based on the result of detection of the fuel amount detection device.

Thus, the amount of supply of the power generation fuel can be controlled in a feedback manner based on the amount of power generation fuel actually detected that contributes to the power generation of the fuel cell, as a consequence of which an optimal amount of power generation fuel can be supplied to the fuel cell so as to achieve the target amount of electric power generation thereof.

In the above control, for example, when the amount of power generation fuel contributing to the power generation of the fuel cell detected by the fuel amount detection device is smaller than a target amount, the supply amount control part increases the amount of power generation fuel supplied by the fuel supply system. On the other hand, when the amount of power generation fuel contributing to the power generation of the fuel cell detected by the fuel amount detection device is larger than the target amount, the supply amount control part may decrease the amount of power generation fuel supplied by said fuel supply system.

Preferably, the internal combustion engine may further comprise a temperature detection device that detects a state of an element related to the temperature of the fuel cell, wherein the supply amount control part controls the amount of power generation fuel supplied by the fuel supply system based on the result of detection of the temperature detection device.

The fuel cell has a suitable temperature for power generation, so it is possible to perform efficient power generation by supplying the power generation fuel when the fuel cell is at such a suitable temperature. In addition, when the temperature of the fuel cell is low, the amount of supply of the power generation fuel may be decreased. That is, when the temperature

of the fuel cell is lower than a prescribed temperature, the supply amount control part may decrease the amount of power generation fuel supplied by the fuel supply system. Here, the prescribed temperature may be a suitable temperature for power generation. Thus, it is possible to suppress the power generation fuel exhausted from the fuel cell without contributing to power generation.

Preferably, the internal combustion engine may further comprise a combustion device, wherein the fuel supply system supplies an exhaust gas discharged from the combustion device to the exhaust passage at a location downstream of the internal combustion engine and upstream of the fuel cell.

By supplying the exhaust gas (burnt gas) from the combustion device to an intermediate portion of the exhaust passage, the burnt gas can be supplied to the fuel cell. Thus, by supplying the burnt gas from the combustion device to the fuel cell, the temperature of the fuel cell can be raised. Accordingly, even if the temperature of the exhaust gas discharged from the engine and the temperature of the fuel cell are low such as at the time of engine starting or the like, the fuel cell is able to start power generation at an earlier stage. Preferably, the exhaust gas (burnt gas) discharged from the combustion device may be supplied to the exhaust passage at a location downstream of the internal combustion engine and upstream of the fuel cell, while combustion in the combustion device is being performed in the state of an air fuel mixture containing excessive fuel (i.e., in a fuel rich state). By supplying the burnt gas to the fuel cell, the unburnt fuel in the combustion device can be supplied as the power generation fuel for the fuel cell. Preferably, the fuel supply system may supply an unburnt gas discharged from the combustion device to the exhaust passage at a location downstream of the internal combustion engine and upstream of the fuel cell, without combusting fuel in the combustion device. With such a construction, the unburnt fuel in the combustion device can also be supplied as the power generation fuel for the fuel cell.

Preferably, the supply amount control part may control the amount of power generation fuel supplied by the fuel supply system by changing an air

fuel ratio of a gas combusted in the combustion device.

The amount of unburnt fuel contained in the burnt gas from the combustion device changes when the air fuel ratio of the gas combusted in the combustion device is changed. Thus, it is possible to change the amount of power generation fuel supplied to the fuel cell by changing the air fuel ratio of the mixture in the combustion device. As a result, the power generation fuel can be supplied in accordance with the target amount of electric power generation of the fuel cell.

In cases where the main purpose is to raise the temperature of the fuel cell such as when the temperature of the fuel cell is lower than a prescribed temperature at which the fuel cell is able to generate electric power, it is desirable to make the air fuel ratio of the gas combusted in the combustion device to be a value in the vicinity of the stoichiometric air fuel ratio. With this measure, a gas of a relatively high temperature can be generated, so that the gas of such a high temperature (burnt gas) can be supplied to the fuel cell. In addition, it is possible to suppress the unburnt fuel exhausted from the combustion device.

Preferably, the internal combustion engine may further comprise a catalyst having oxidation capability that is installed on the exhaust passage at a location upstream of the fuel cell and downstream of the fuel supply system.

By this catalyst, the unburnt fuel from the internal combustion engine and/or the power generation fuel from the fuel supply system can be oxidized, so that the temperature of the fuel cell at the downstream side of the engine and fuel supply system can be raised by the heat of reactions at that time. Accordingly, even if the temperature of the exhaust gas discharged from the engine and the temperature of the fuel cell are low at the time of engine starting or the like, the fuel cell is able to start power generation at an earlier stage. Moreover, the unburnt fuel from the internal combustion engine and the power generation fuel from the fuel supply system react with oxygen in the catalyst to decrease the oxygen concentration of the exhaust gas, so that the amount of electric power generation of the fuel cell can be increased. Further, since the power generation fuel is reformed, it is possible to make the power

generation fuel react easily in the fuel cell, as a result of which the electrical efficiency of the fuel cell can be improved.

In case where a catalyst having oxidation capability is installed on the exhaust passage at a location upstream of the fuel cell and downstream of the fuel supply system, when the internal combustion engine is operated with a mixture of a rich air fuel ratio, the amount of power generation fuel supplied by the fuel supply system may be adjusted by making the air fuel ratio of the gas combusted in the combustion device to be a lean air fuel ratio.

Oxygen is supplied to the catalyst having oxidation capability by combusting the mixture of a lean air fuel ratio in the combustion device. By supplying oxygen in this manner, the unburnt fuel from the internal combustion engine can be oxidized, thus making it possible to adjust the amount of power generation fuel supplied to the fuel cell.

Preferably, the internal combustion engine may further comprise a catalyst having oxidation capability that is installed on the exhaust passage at a location downstream of the fuel cell.

With this catalyst, it becomes possible to oxidize the power generation fuel exhausted from the fuel cell without contributing to power generation, whereby the power generation fuel can be suppressed from being discharged into the ambient atmosphere.

Preferably, in case where a catalyst having oxidation capability is installed on the exhaust passage at a location downstream of the fuel cell, the internal combustion engine may further comprise an oxygen supply device that supplies oxygen to the catalyst having oxidation capability.

In the case of the catalyst having oxidation ability, the higher the oxygen concentration of the exhaust gas passing through the catalyst, the higher does the oxidation capability of the catalyst becomes, and hence the oxidation capability of the catalyst can be improved by supplying oxygen to the catalyst. In this case, the oxygen discharged from an air electrode side of the fuel cell may be supplied to the catalyst.

Preferably, the internal combustion engine may further comprise a heat exchanger installed on the exhaust passage at a location downstream of the

fuel cell.

The temperature of the gas exhausted from the fuel electrode side of the fuel cell operating at high temperature is high, so the heat of this gas can be collected by the heat exchanger. As a result, the system efficiency of the entire internal combustion engine can be improved. For example, by raising the temperature of cooling water for the internal combustion engine by use of the heat collected by the heat exchanger, the warming up of the internal combustion engine can be facilitated.

Preferably, the internal combustion engine may further comprise an air supply passage that has the heat exchanger installed thereon and is connected with an inlet side of an air electrode of the fuel cell, wherein air whose temperature is raised due to the heat of an exhaust gas in the heat exchanger is supplied into the air electrode of the fuel cell through the air supply passage.

Thus, air can be supplied to the fuel cell while suppressing a temperature drop thereof, as a result of which the electrical efficiency of the fuel cell can be improved.

Preferably, an air supply passage with the heat exchanger installed thereon may be connected with the combustion device, so that air whose temperature is raised in the heat exchanger can be supplied into the combustion device through the air supply passage. With such an arrangement, the evaporation of the fuel in the combustion device can be facilitated with the result that the combustion state of the mixture in the combustion device can be stabilized.

The above and other objects, features and advantages of the present invention will become more readily apparent to those skilled in the art from the following detailed description of preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a first embodiment of the present invention.

Fig. 2 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a second embodiment of the present invention.

Fig. 3 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a third embodiment of the present invention.

Fig. 4 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a fourth embodiment of the present invention.

Fig. 5 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a fifth embodiment of the present invention.

Fig. 6 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a sixth embodiment of the present invention.

Fig. 7 is a view showing the flow of signals around an ECU according to the first embodiment of the present invention.

Fig. 8 is a view showing the schematic construction of an internal combustion engine with intake and exhaust systems according to a seventh embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of according to the present invention will be described while referring to the accompanying drawing. Here, reference will be made to the case where an internal combustion engine with a fuel cell according to the present invention is applied to a diesel engine used for driving a vehicle.

<FIRST EMBODIMENT>

Fig. 1 is a view that shows the schematic construction of an internal combustion engine with intake and exhaust systems according to a first embodiment of the present invention. The internal combustion engine (hereinafter also referred to simply as engine), generally designated at 1 in Fig. 1, is a water-cooled four-cycle diesel engine. Connected with the engine 1 is

an exhaust passage 2 for discharging an exhaust gas exhausted from the engine 1 into the ambient atmosphere. A fuel cell 3 is installed on an intermediate portion of the exhaust passage 2. This fuel cell 3 is electrically connected to accessories 4 through a battery 5 for supplying electric power to the accessories 4. Here, note that in this embodiment, a solid oxide fuel cell, which is simple in structure and control and does not require a catalyst for the fuel cell, and in which fuel can be reformed inside the fuel cell, is adopted as the fuel cell (hereinafter referred to as SOFC) 3.

The SOFC 3 is constructed such that it includes three kinds of oxide electrolytes, i.e., a fuel electrode 3a, an electrolyte 3b, and an air electrode 3c.

In addition, an air pump 6 for sending air to the air electrode 3c of the SOFC 3 is connected with the SOFC 3 through an air supply passage 7. The air pump 6 receives electric power from the battery 5, and is thereby operated to discharge air to the air supply passage 7.

A combustion device 9 is connected at its exhaust side with the exhaust passage 2 at a location between the SOFC 3 and the engine 1 through an introduction passage 8. The air pump 6 is connected with an intake side of the combustion device 9 through the air supply passage 7. Moreover, the combustion device 9 is provided with a fuel injection valve 10 for injecting fuel into the combustion device 9. The fuel injection valve 10 is connected to a fuel pump 11 which serves to feed fuel under pressure to the fuel injection valve 10. In addition, the combustion device 9 is also provided with a spark plug 12 for generating an electric spark based on a signal from an electronic control unit (ECU) 13 to be described later.

In the combustion device 9 constructed in this manner, fuel is pressure fed from the fuel pump 11 to the fuel injection valve 10, so that it is injected from the fuel injection valve 10 into the combustion device 9. The fuel thus injected mixes with air supplied from the air pump 6 to the combustion device 9 to form an air fuel mixture therein. When an electric spark is generated by the spark plug 12, the air fuel mixture is thereby ignited or fired to burn or combust in the combustion device 9. Thereafter, by means of air and fuel being further supplied into the gas (i.e., air fuel mixture) under combustion, the combustion

can be made continuously with the gas under combustion acting as an ignition source. The burnt gas thus produced by combustion is introduced into the exhaust passage 2 through the introduction passage 8.

Here, note that in this embodiment, an electric spark may not be generated by the spark plug 12, so that the air fuel mixture being unburnt can be discharged to the introduction passage 8 as it is.

The gas introduced into the exhaust passage 2 while being burnt or unburnt can be used as power generation fuel of the SOFC 3.

Here, the power generation fuel thus introduced into the SOFC 3 reacts with steam or water vapor on the fuel electrode 3a, so that it is reformed into hydrogen (H_2) and carbon monoxide (CO). Thus, in the SOFC 3, it is possible to reform the power generation fuel therein. On the other hand, air is supplied from the air pump 6 to the air electrode 3c. In the air electrode 3c, the atmospheric oxygen dissociates into oxygen ions (O^{2-}) on an interface with the electrolyte 3b, and the oxygen ions (O^{2-}) thus generated move toward the fuel electrode 3a side in the electrolyte 3b. The oxygen ions (O^{2-}) having arrived at an interface between the electrolyte 3b and the fuel electrode 3a react with hydrogen (H_2) and carbon monoxide (CO) to generate water (H_2O) and carbon dioxide (CO_2). The power generation of the SOFC 3 is performed by taking out electrons discharged at this time. Thus, according to the SOFC 3, the chemical energy of the power generation fuel is converted directly into electrical energy, so a loss due to the energy conversion is small, making it possible to generate electric power at high efficiency. Such power generation in the SOFC 3 is performed at temperatures from 700 to 1,000 °C, for example.

Installed on the exhaust passage 2 at the downstream side of the SOFC 3 are an air fuel ratio sensor 15 that outputs a signal corresponding to the air fuel ratio of the exhaust gas, and an exhaust gas temperature sensor 16 that outputs a signal corresponding to the temperature of the exhaust gas.

The ECU 13 for controlling the engine 1 is provided in conjunction with the engine 1 as constructed above. The ECU 13 controls the operating state

of the engine 1 according to the operating condition of the engine 1 and the driver's request.

A variety of kinds of sensors such as ones mentioned above are connected to the ECU 13 through electric wiring, so that the output signals of the various sensors are input to the ECU 13. Also, the fuel injection valve 10, the spark plug 12 and the fuel pump 11 are connected to the ECU 13 through electric wiring, so that the operations of these members are controlled by the ECU 13. For example, when a drive current is applied to the fuel injection valve 10 under the control of a signal from the ECU 13, the fuel injection valve 10 is driven to open, as a result of which fuel is injected from the fuel injection valve 10 into the combustion device 9. In addition, a fuel cell ECU (hereinafter referred to as FC ECU) 14 for controlling the SOFC 3 is connected to the ECU 13, so that the SOFC 3 is driven to operate under the control of a signal from the FC ECU 14.

A part of electric power provided by the power generation of the SOFC 3 is once accumulated in the battery 5. The accessories 4 such as an electric water pump, an electric compressor for use with an air conditioner, an electric oil pump, an electric pump for power steering and the like are electrically connected to the battery 5, so that electric power is supplied from the battery 5 to these accessories.

However, in a conventional internal combustion engine with a fuel cell in an exhaust system, the unburnt fuel contained in the exhaust gas exhausted from the internal combustion engine has been used as power generation fuel of the fuel cell. Accordingly, when the fuel cell needs a large amount of power generation fuel, it is necessary to exhaust a larger amount of unburnt fuel from the internal combustion engine by making the internal combustion engine operate with a mixture of a rich air fuel ratio.

However, for example, a conventional diesel engine is ordinarily operated with a mixture of a lean air fuel ratio, so the oxygen concentration of the exhaust gas is high and the amount of unburnt fuel is limited, thus making it difficult to obtain a necessary amount of electric power.

Moreover, when an internal combustion engine has been operated at a

rich-side air fuel ratio, in which the amount of fuel is more than that at the air fuel ratio at the time of ordinary operation, in order to supply the power generation fuel to the fuel cell, torque fluctuation and/or the deterioration of emissions has occasionally been induced.

In addition, it might be difficult to operate the internal combustion engine at a rich-side air fuel ratio depending upon the operating condition of the internal combustion engine, and in such a case, it was impossible to secure required electric power.

In the past, the main purpose was to use an internal combustion engine as a reformer for power generation fuel to obtain an output from a fuel cell in preference to obtaining an output from the internal combustion engine. Accordingly, the operating condition of the internal combustion engine had been changed so as to generate electricity with the fuel cell, and hence it was difficult to obtain enough power from the internal combustion engine. However, when a comparison is made between the internal combustion engine and the fuel cell with the same mass or the same volume, the output obtained from the internal combustion engine is greater than that obtained from the fuel cell. Therefore, considering the installation of the fuel cell on a vehicle, it is advantageous to mainly use the output from the internal combustion engine for the driving power of the vehicle from the point of view of the mass, size, etc.

In this respect, according to this embodiment, the exhaust gas (i.e., burnt gas) discharged from the combustion device 9 can be supplied to the SOFC 3 as power generation fuel without changing the operating condition of the engine 1.

Further, in this embodiment, it is possible to adjust the amount of power generation fuel supplied to the SOFC 3 by means of the amount of fuel injected from the fuel injection valve 10 into the combustion device 9. That is, assuming that the amount of air supplied from the air pump 6 is constant, the air fuel ratio of the mixture in the combustion device 9 is decided by the amount of fuel injected from the fuel injection valve 10. Here, note that in this embodiment, the fuel injection valve 10 is driven to open intermittently under the control of the ECU 13, so that the amount of fuel supplied to the

combustion device 9 is controlled by adjusting the valve open time and the valve closure time of the fuel injection valve 10 at this time. That is, the longer the valve open time of the fuel injection valve 10, and the shorter the valve closure time thereof, the greater does the amount of fuel supplied to the combustion device 9 become. On the other hand, the shorter the valve open time of the fuel injection valve 10, and the longer the valve closure time thereof, the smaller does the amount of fuel supplied to the combustion device 9 become. In addition, the amount of air supplied per unit time from the air pump 6 to the combustion device 9 can be obtained beforehand by experiments or the like. Accordingly, the air fuel ratio of the mixture in the combustion device 9 can be controlled by adjusting the valve open time of the fuel injection valve 10.

In view of the above, the relation between the target air fuel ratio that is an air fuel ratio to be targeted or attained in the air fuel mixture in the combustion device 9 and the valve open time and the valve closure time of the fuel injection valve 10 is mapped beforehand, and the valve open time and the valve closure time of the fuel injection valve 10 may be determined by substituting a desired target value for the target air fuel ratio in the map.

Moreover, the relation between the target amount of electric power generation that is an amount of electric power generation to be targeted or obtained in the SOFC 3 and the valve open time and the valve closure time of the fuel injection valve 10 is mapped beforehand. The valve open time and the valve closure time of the fuel injection valve 10 may be determined by substituting a desired target value for the target amount of electric power generation in the map.

Here, note that when power generation fuel is supplied to the SOFC 3, combustion may be carried out with the air fuel ratio of the mixture in the combustion device 9 being set to a fuel-excess air fuel ratio (rich air fuel ratio). The unburnt fuel at this time, i.e., hydrocarbon (HC) remaining unburnt, is supplied to the SOFC 3 through the introduction passage 8 and the exhaust passage 2. The hydrocarbon supplied at this time is reformed due to the high temperature in the combustion device 9, so it becomes easy to react in the

SOFC 3. Moreover, carbon monoxide (CO) generated during the combustion of the mixture of a rich air fuel ratio in the combustion device 9 also serves as power generation fuel for the SOFC 3. Further, when there is steam or water vapor in the combustion device 9, hydrogen (H₂) is generated upon combustion of the mixture therein. The hydrogen thus generated also serves as power generation fuel for the SOFC 3.

Here, note that in this embodiment, when power generation fuel is supplied to the SOFC 3, the mixture may be discharged from the combustion device 9 without being combusted or burnt therein. In this case, the amount of fuel injected from the fuel injection valve 10 becomes equal to the amount of power generation fuel supplied to the SOFC 3. Thus, the power generation fuel can be supplied to the SOFC 3 by the fuel injection from the fuel injection valve 10. In this connection, if the relation between the target amount of electric power generation and the valve open time and the valve closure time of the fuel injection valve 10 is obtained and mapped beforehand, it is possible to generate a sufficient amount of electric power to meet a target power generation amount by adjusting the valve open time and the valve closure time of the fuel injection valve 10 in an appropriate manner.

Furthermore, the power generation in the SOFC 3 is performed at temperatures from 700 to 1,000°C for example, as stated above. Accordingly, when the temperature of the SOFC 3 is low, it is necessary to raise the temperature of the SOFC 3 to an appropriate temperature. Here, note that if the temperature of the SOFC 3 is caused to rise due solely to the exhaust gas from the engine 1, it takes time until the SOFC 3 reaches a prescribed temperature at which the SOFC 3 is able to carry out power generation since in the diesel engine, the combustion temperature is low and hence the temperature of the exhaust gas is low. In this respect, however, according to this embodiment, a high temperature gas discharged as a result of the mixture in the combustion device 9 being combusted can be supplied to the SOFC 3, so the temperature of the SOFC 3 can be raised more quickly than in the above case. As a consequence, power generation can be started at an

earlier stage even when the temperature of the SOFC 3 is low. Here, note that in case where it is the main purpose to raise the temperature of the SOFC 3, it is desirable to combust or burn the mixture in the combustion device 9 at an air fuel ratio in the vicinity of the stoichiometric air fuel ratio. By combusting the mixture under such a condition, a gas of a relatively high temperature can be generated, so that the gas of such a high temperature (burnt gas) can be supplied to the SOFC 3. In addition, it is possible to suppress the unburnt fuel exhausted from the combustion device 9 by combusting the mixture at an air fuel ratio in the vicinity of the stoichiometric air fuel ratio.

Moreover, according to this embodiment, the exhaust gas from the engine 1 is also supplied to the fuel electrode 3a, so that the temperature of the SOFC 3 can be raised due to the heat of the exhaust gas, and a part of the exhaust gas from the engine 1 can be used as power generation fuel.

Here, note that in this embodiment, the amount of power generation fuel supplied to the SOFC 3, i.e., the valve open time and the valve closure time of the fuel injection valve 10, may be controlled in a feedback manner based on the output signal of the air fuel ratio sensor 15 installed on the exhaust passage 2 at a location downstream of the SOFC 3.

That is, when the output signal of the air fuel ratio sensor 15 is higher than a target air fuel ratio, the valve open time of the fuel injection valve 10 is lengthened and the valve closure time thereof is shortened. On the other hand, when the output signal of the air fuel ratio sensor 15 is lower than the target air fuel ratio, the valve open time of the fuel injection valve 10 is shortened and the valve closure time thereof is lengthened.

In other words, when the amount of fuel contributing to the power generation of the SOFC 3 is small, the amount of power generation fuel to be supplied is increased, whereas when the amount of fuel contributing to the power generation of the SOFC 3 is large, the amount of power generation fuel to be supplied is decreased. According to such fuel control, the amount of supply of the power generation fuel can be controlled based on the amount of power generation fuel that contributes to the power generation by the SOFC 3.

As a result, an optimal amount of power generation fuel can be supplied to the SOFC 3 so as to achieve a target amount of electric power generation of the SOFC 3.

Similarly, in this embodiment, the valve open time and the valve closure time of the fuel injection valve 10 may be controlled in a feedback manner based on the output signal of the exhaust gas temperature sensor 16 installed on the exhaust passage 2 at a location downstream of the SOFC 3.

That is, based on the output signal of the exhaust gas temperature sensor 16, it is possible to determine whether the temperature of the SOFC 3 has risen to a temperature at which the SOFC 3 is able to perform electric power generation. The temperature of the SOFC 3 is raised by combusting the mixture of the stoichiometric air fuel ratio in the combustion device 9 until the SOFC 3 rises to a temperature at which it is able to perform power generation. After the temperature of the SOFC 3 has risen up to the temperature at which the SOFC 3 is able to carry out power generation, a mixture of a rich air fuel ratio is combusted in the combustion device 9, so that electricity is generated by the SOFC 3.

As a result, at cold engine start or the like, the temperature of the SOFC 3 can be raised further rapidly up to the temperature at which electricity can be generated by the SOFC 3. Further, the temperature of the SOFC 3 can be controlled to be suitable for power generation, that is, a temperature at which the SOFC 3 has high electrical efficiency. As a result, reduction in the electrical efficiency can be suppressed.

Here, note that when the temperature of the SOFC 3 is lower than the temperature suitable for power generation, the amount of supply of the power generation fuel may be decreased by reducing the amount of fuel to be injected from the fuel injection valve 10. By doing so, it is possible to suppress the unburnt fuel exhausted from the SOFC 3 without contributing to power generation.

As described above, according to this embodiment, the power generation fuel can be supplied to the SOFC 3 without regard to the operating condition of the engine 1. In addition, an optimal amount of power generation

fuel can be supplied to the SOFC 3 so as to achieve a target amount of electric power generation thereof. Moreover, the temperature of the SOFC 3 can be raised more quickly, whereby the power generation of the SOFC 3 can be started at an earlier stage. Further, the amount of supply of the power generation fuel can be controlled in a feedback manner by the air fuel ratio sensor 15 and/or the exhaust gas temperature sensor 16. Here, reference will be made to the flow of signals around the ECU 13 in this embodiment while referring to Fig. 7.

In Fig. 7, a dotted line arrow (1) represents the flow of a signal from the ECU 13 to the fuel injection valve 10. A dotted line arrow (2) represents the flow of a signal from the air fuel ratio sensor 15 to the ECU 13. A dotted line arrow (3) represents the flow of a signal from the exhaust gas temperature sensor 16 to the ECU 13. A solid line arrow in Fig. 7 represents the supply of fuel from the fuel injection valve 10 to the combustion device 9.

In this embodiment, as stated above, fuel is injected from the fuel injection valve 10 into the combustion device 9, and the unburnt fuel contained in the gas exhausted from the combustion device 9 is supplied as power generation fuel to the SOFC 3. That is, the fuel injection valve 10 and the combustion device 9 together constitute a fuel supply system 101 according to the present invention. The valve open time and the valve closure time of the fuel injection valve 10 are controlled in the above-mentioned manner by running a control program stored in the ECU 13, so that the amount of fuel to be injected from the fuel injection valve 10 can be controlled in an appropriate manner. As a result, the amount of power generation fuel supplied to the SOFC 3 is adjusted. That is, the control program constitutes a supply amount control part 201 according to the present invention.

Furthermore, in this embodiment, the supply amount control part 201 may control the amount of fuel to be injected from the fuel injection valve 10 based on the output signal of the air fuel ratio sensor 15 and/or the output signal of the exhaust gas temperature sensor 16, as mentioned above. That is, the air fuel ratio sensor 15 constitutes a fuel amount detection device according to the present invention, and the exhaust gas temperature sensor 16

constitutes a temperature detection device according to the present invention.

<SECOND EMBODIMENT>

A second embodiment of the present invention is different from the first embodiment in that it is provided with an oxidation catalyst 17 installed on the exhaust passage 2 at a location between the introduction passage 8 and the SOFC 3, as shown in Fig. 2. Here, note that in this second embodiment, the basic structure of the internal combustion engine, to which the present invention is applied, and the rest of hardware are common with those of the above-mentioned first embodiment, and hence an explanation thereof is omitted.

Fig. 2 is a view that illustrates the schematic construction of the engine 1 and its intake and exhaust systems according to this second embodiment.

Unburnt fuel, which serves as power generation fuel for the SOFC 3, is supplied from the engine 1 and/or the combustion device 9 to the oxidation catalyst 17, whereby the unburnt fuel is oxidized by the oxidation catalyst 17. The temperature of the exhaust gas discharged from the engine 1 is raised by the heat of reactions generated at this time, so that the temperature of the SOFC 3 rises due to the exhaust gas flowing therein. As a result, even if the temperature of the exhaust gas discharged from the engine 1 and the temperature of the SOFC 3 are low, the temperature of the SOFC 3 can be raised more quickly, so the power generation of the SOFC 3 is able to be started at an earlier stage. In addition, a part of the unburnt fuel is reformed by the oxidation catalyst 17, so that the unburnt fuel thus reformed can be supplied to the SOFC 3. The reformed unburnt fuel is easy to react at the fuel electrode 3a, so the electrical efficiency of the SOFC 3 can be improved. Furthermore, the unburnt fuel from the engine 1 and/or the combustion device 9 reacts with oxygen in the oxidation catalyst 17, so the oxygen concentration of the exhaust gas is thereby decreased, thus making it possible to increase the amount of electric power generation of the SOFC 3.

Here, note that in this embodiment, the unburnt fuel discharged from the combustion device 9 may be obtained by the combustion of a mixture containing therein an excessive amount of fuel, or it may also be obtained by

discharging the fuel injected by the fuel injection valve 10 from the combustion device 9 in its unburnt state.

Moreover, in cases where the engine 1 is operated with a mixture of a rich air fuel ratio, a mixture of a lean air fuel ratio may be combusted in the combustion device 9, so that the oxidation catalyst 17 can be supplied with oxygen to oxidize the unburnt fuel from the engine 1, thus making it possible to adjust the amount of unburnt fuel supplied to the SOFC 3.

Here, it is preferable to adopt a small-sized catalyst as the oxidation catalyst 17 for the purpose of raising the temperature of the oxidation catalyst 17 at an early stage.

<THIRD EMBODIMENT>

A third embodiment of the present invention is different from the second embodiment in that it is provided with an oxidation catalyst 18 installed on the exhaust passage 2 at a location downstream of the SOFC 3, as shown in Fig. 3. Here, note that in this third embodiment, the basic structure of the internal combustion engine, to which the present invention is applied, and the rest of hardware are common with those of the above-mentioned first embodiment, and hence an explanation thereof is omitted.

Fig. 3 is a view that illustrates the schematic construction of the engine 1 and its intake and exhaust systems according to this third embodiment.

In case where the air fuel ratio sensor 15 or the exhaust gas temperature sensor 16 is installed on the exhaust passage 2, the components of the exhaust gas are changed in the oxidation catalyst 18 thereby to influence the output of the sensor 15 or 16. To avoid such an influence, the oxidation catalyst 18 is arranged at the downstream side of the sensor 15 or 16.

In the SOFC 3, the whole of the power generation fuel (unburnt fuel from engine 1 and/or the combustion device 9) supplied to the SOFC3 does not react, and some of the power generation fuel may pass through the SOFC 3 without undergoing reactions. If a part of the power generation fuel is discharged into the atmosphere, the emissions discharged from the engine 1 into the atmosphere are deteriorated. In this respect, however, according to

this embodiment, by the provision of the oxidation catalyst 18 arranged at the downstream side of the SOFC 3, the power generation fuel discharged from the SOFC 3 without undergoing reactions therein can be oxidized by the oxidation catalyst 18, whereby the exhaust gas to be discharged into the atmosphere can be purified.

Further, the oxidation catalyst 18, being arranged at the downstream side of the SOFC 3, is maintained at a high temperature by the heat from the SOFC 3, so it is possible to carry out stable purification of the exhaust gas.

<FOURTH EMBODIMENT>

A fourth embodiment of the present invention is different from the third embodiment in that the gas (cathode off-gas) exhausted from the air electrode 3c side of the SOFC 3 is introduced into the oxidation catalyst 18. Here, note that in this fourth embodiment, the basic structure of the internal combustion engine, to which the present invention is applied, and the rest of hardware are common with those of the above-mentioned first embodiment, and hence an explanation thereof is omitted.

Fig. 4 is a view that illustrates the schematic construction of the engine 1 and its intake and exhaust systems according to this fourth embodiment.

In this embodiment, a portion of the exhaust passage 2 between the SOFC 3 and the oxidation catalyst 18 is connected with an outlet side of the air electrode 3c through an air introduction passage 19, so that the oxygen discharged from the air electrode 3c side is introduced into the oxidation catalyst 18. In case where the air fuel ratio sensor 15 or the exhaust gas temperature sensor 16 is installed on the exhaust passage 2, the components of the exhaust gas are changed in the oxidation catalyst 18 thereby to influence the output of the sensor 15 or 16. To avoid such an influence, the air introduction passage 19 is arranged at the downstream side of the sensor 15 or 16.

Here, note that the exhaust gas from the fuel electrode 3a side may have a low oxygen concentration depending upon the operating state of the engine 1 or the power generation state of the SOFC 3. Thus, when the oxygen concentration of the exhaust gas from the fuel electrode 3a side is low,

the oxidation ability of the oxidation catalyst 18 might be reduced, making it difficult to oxidize the unburnt fuel. In this case, there is a fear that if oxygen is supplied to the oxidation catalyst 18 with the operating condition of the engine 1 or the power generation state of the SOFC 3 being changed, necessary torque might not be obtained from the engine 1, and a target amount of electric power generation of the SOFC 3 might become unable to be achieved.

In this connection, however, according to this embodiment, the oxygen contained in the air from the air electrode 3c side can be introduced into the oxidation catalyst 18, so it is possible to suppress the deterioration of emissions, which would otherwise be caused due to a lack of oxygen in the oxidation catalyst 18. In addition, it is possible to supply oxygen to the oxidation catalyst 18 without depending upon the operating condition of the engine 1 and the power generation state of the SOFC 3.

Here, note that in this embodiment, air supplied by the air pump 6 may be introduced into the oxidation catalyst 18.

Thus, in this embodiment, the air introduction passage 19 or the air pump 6 constitutes an air supply system according to the present invention.

<FIFTH EMBODIMENT>

A fifth embodiment of the present invention is different from the fourth embodiment in that it is provided with a heat exchanger 20 installed on the exhaust passage 2 at a location downstream of the oxidation catalyst 18, as shown in Fig. 5. Here, note that in this fifth embodiment, the basic structure of the internal combustion engine, to which the present invention is applied, and the rest of hardware are common with those of the above-mentioned first embodiment, and hence an explanation thereof is omitted.

Fig. 5 is a view that illustrates the schematic construction of the engine 1 and its intake and exhaust systems according to this fifth embodiment.

In this embodiment, the heat exchanger 20 is arranged on the exhaust passage 2 at a location downstream of the oxidation catalyst 18, and a bypass passage 21 for bypassing the exhaust gas around the heat exchanger 20 has one end and the other end thereof connected with the exhaust passage 2 at

locations on the upstream side and the downstream side of the heat exchanger 20, respectively. A three-way valve 22 for selectively passing the exhaust gas through either one of the bypass passage 21 and the heat exchanger 20 is installed on the exhaust passage 2 at a location thereof at which the bypass passage 21 is connected at the other end thereof with the exhaust passage 2 on the downstream side of the heat exchanger 20.

A cooling water passage 23 in which coolant or water for cooling the engine 1 circulates is connected with the heat exchanger 20. The cooling water passage 23 is connected with the engine 1 and a heater core 24.

Here, note that the operating temperature of the SOFC 3 is high, and hence a gas of high temperature is exhausted from the fuel electrode 3a side of the SOFC 3. Accordingly, during the time when the SOFC 3 performs power generation, the temperature of the exhaust gas exhausted from the engine 1, even if low, is raised in the SOFC 3, and hence the temperature of the exhaust gas at the downstream side of the SOFC 3 becomes high. On the other hand, even if the temperature of the exhaust gas from the engine 1 is high, the heat from the engine 1 can be collected by the heat exchanger 20 arranged on the exhaust passage 2. Thus, the heat of the exhaust gas from the engine 1 and the SOFC 3 can be collected by the single heat exchanger 20. As a result, installability of the heat exchanger on the vehicle can be improved.

In this embodiment, the cooling water of the engine 1 is caused to circulate through the heat exchanger 20, so that heat exchange is performed between the exhaust gas of high temperature and the cooling water thereby to raise the temperature of the cooling water. That is, as the exhaust gas of high temperature is introduced into the heat exchanger 20, the temperature of the cooling water is raised by the heat exchanger 20. Thus, it is possible to improve the heating performance of the vehicle by circulating the cooling water thus raised in temperature in the heater core 24 through the cooling water passage 23. Moreover, when the temperature of the engine 1 is low at the time of engine starting or the like, it is possible to heat the engine 1 quickly by making the cooling water of high temperature circulate through the engine 1. Further, even if the heat exchanger 20 is reduced in size, such an

advantageous effect can be achieved to a satisfactory extent since the exhaust gas of high temperature is circulated through the heat exchanger 20.

Here, note that when the cooling water temperature becomes too high, it becomes unable to cool the engine 1 to a satisfactory extent, giving rise to so-called overheating. Accordingly, the three-way valve 22 is driven to operate before the cooling water temperature becomes too high, so that the exhaust gas is passed to the bypass passage 21. By doing so, it is possible to suppress the occurrence of overheating. Furthermore, in the case of the provision of the exhaust gas temperature sensor 16, the exhaust gas may be passed through the bypass passage 21 by means of the three-way valve 22 when the temperature of the exhaust gas detected by the exhaust gas temperature sensor 16 is higher than a prescribed temperature.

<SIXTH EMBODIMENT>

A sixth embodiment of the present invention is different from the fifth embodiment in that heat exchange between the exhaust gas and air is performed in the heat exchanger 20. Here, note that in this sixth embodiment, the basic structure of the internal combustion engine, to which the present invention is applied, and the rest of hardware are common with those of the above-mentioned first embodiment, and hence an explanation thereof is omitted.

Fig. 6 is a view that illustrates the schematic construction of the engine 1 and its intake and exhaust systems according to this sixth embodiment.

In this embodiment, the heat exchanger 20 is arranged on the exhaust passage 2 at a location downstream of the oxidation catalyst 18, and a bypass passage 21 for bypassing the exhaust gas around the heat exchanger 20 has one end and the other end thereof connected with the exhaust passage 2 at locations on the upstream side and the downstream side of the heat exchanger 20, respectively. A three-way valve 22 for selectively passing the exhaust gas through either one of the bypass passage 21 and the heat exchanger 20 is installed on the exhaust passage 2 at a location thereof at which the bypass passage 21 is connected at the other end thereof with the exhaust passage 2 on the downstream side of the heat exchanger 20.

The heat exchanger 20 is connected at its inlet side with the air pump 6 through the air supply passage 7, and at its outlet side with an inlet side of the air electrode 3c of the SOFC 3 through the air supply passage 7. Also, the air supply passage 7 connected with the outlet side of the heat exchanger 20 is branched on its way to the SOFC 3 to be connected with the combustion device 9 through a heat exchanger 25.

A cooling water passage 23 in which coolant or water for cooling the engine 1 circulates is connected with the heat exchanger 25. The cooling water passage 23 is connected with the engine 1 and the heater core 24.

Here, note that the operating temperature of the SOFC 3 is high, and hence a gas of high temperature is exhausted from the fuel electrode 3a side of the SOFC 3. Accordingly, during the time when the SOFC 3 performs power generation, the temperature of the exhaust gas exhausted from the engine 1, even if low, is raised in the SOFC 3, and hence the temperature of the exhaust gas at the downstream side of the SOFC 3 becomes high. In this embodiment, heat exchange is performed between the exhaust gas of high temperature and the air discharged from the air pump 6, whereby the temperature of the air supplied to the SOFC 3 and the combustion device 9 can be raised.

With such a construction, as the exhaust gas of high temperature is introduced into the heat exchanger 20, the temperature of air is raised by the heat exchanger 20. Thus, by introducing the air thus raised in temperature into the air electrode 3c of the SOFC 3, it is possible to supply the air to the SOFC 3 while suppressing a temperature drop thereof, as a result of which the electrical efficiency of the SOFC 3 can be improved.

In addition, the evaporation of fuel in the combustion device 9 is facilitated by supplying the air of high temperature to the combustion device 9, so that combustion in the combustion device 9 can be further stabilized. However, when the temperature of the air supplied to the combustion device 9 becomes too high, the oxygen concentration of the air is reduced. To avoid this, according to this embodiment, after heat exchange between the air of high temperature and the cooling water has been made in the heat exchanger 25,

the air thus lowered in temperature is supplied to the combustion device 9. As a result, combustion in the combustion device 9 can be further stabilized. On the other hand, when the mixture is caused to discharge from the combustion device 9 without undergoing combustion therein, the evaporation of the fuel in the mixture can be facilitated, so that the fuel can be made easy to react in the SOFC 3.

As can be seen from the foregoing discussion, in an internal combustion engine with a fuel cell in an exhaust system according to the present invention, it is possible to supply power generation fuel to the fuel cell without regard to the operating condition of the internal combustion engine. In addition, the amount of power generation fuel supplied to the fuel cell can be increased or decreased without regard to the operating condition of the internal combustion engine, so that an amount of power generation fuel corresponding to a target amount of power generation can be supplied. Further, by introducing the exhaust gas from a combustion device into the fuel cell, the temperature of the fuel cell can be raised more quickly, whereby the power generation of the fuel cell can be accordingly started at an earlier stage.

While the invention has been described in terms of preferred embodiments, those skilled in the art will recognize that the invention can be practiced with modifications within the spirit and scope of the appended claims.

<SEVENTH EMBODIMENT>

A seventh embodiment of the present invention is different from the first embodiment in that, in place of the combustion device 9 in the first embodiment, this embodiment includes a fuel adding injector 26 disposed between the engine 1 and the SOFC 3 in the exhaust passage 2 for adding the fuel thereto. Further, the heat exchanger 20 is disposed at the downstream side of the SOFC 3 in the exhaust passage 2. Here, note that in this embodiment, the basic structure of the internal combustion engine, to which the invention is applied and rest hardware are common with those of the above-mentioned first embodiment, and hence an explanation thereof is omitted.

Fig. 8 is a view that illustrates the schematic construction of the engine 1

and its intake and exhaust systems according to this seventh embodiment.

This embodiment includes the fuel adding injector 26 between the engine 1 and the SOFC 3 in the exhaust passage 2. The fuel is supplied from the fuel pump 11 to this fuel adding injector 26. Further, this fuel adding injector 26 is electrically connected with the ECU 13 and operated by the signals from the ECU 13, thereby the fuel adding is controlled. Thus, the fuel added to the exhaust passage 2 can be used as power generation fuel for the SOFC 3.

Accordingly, with this embodiment, the fuel added by the fuel adding injector 26 can be supplied to the SOFC 3 as power generation fuel without changing the operation condition of the engine 1. Further, the exhaust gas from the engine 1 can be introduced into the SOFC 3, thereby the temperature of the SOFC 3 can be raised by a high temperature of the exhaust gas, and, still further, portion of the exhaust gas from the engine 1 can be used as the power generation fuel.

Here, a quantity of power generation fuel supplied to the SOFC 3 can be adjusted by a quantity of the fuel injected from the fuel adding injector 26. Specifically, with this embodiment, a valve of the fuel adding injector 26 is opened intermittently, and the fuel quantity to be added to the exhaust passage 2 is adjusted by adjusting the valve open time and the valve closure time of the valve of the fuel adding injector 26. At this time, as the longer the valve open time and the shorter the valve closure time, the greater does the amount of fuel quantity to be supplied to the SOFC 3 become. On the other hand, as the shorter the valve open time and the longer the valve closure time, the smaller does the amount fuel quantity to be supplied to the SOFC 3 become.

Thus, a relationship between the target amount of electric power generation of the SOFC 3 and the valve open and closure times of the fuel adding injector 26 may be prepared in a map form in advance, and the valve open time and the valve closure time of the fuel adding injector 26 may be determined by substitution of the target amount of electric power generation. In this manner, it becomes possible to perform power generation to meet the target amount of electric power generation.

Further, this embodiment includes the heat exchanger 20 at the

downstream side of the SOFC 3 in the exhaust passage 2. Moreover, and a bypass passage 21 for bypassing the exhaust gas around the heat exchanger 20 has one end and the other end thereof connected with the exhaust passage 2 at locations on the upstream side and the downstream side of the heat exchanger 20, respectively. A three-way valve 22 for selectively passing the exhaust gas through either one of the bypass passage 21 and the heat exchanger 20 is installed on the exhaust passage 2 at a location thereof at which the bypass passage 21 is connected at the other end thereof with the exhaust passage 2 on the downstream side of the heat exchanger 20.

The heat exchanger 20 is provided with an unillustrated air intake port, and heat exchange is performed in the heat exchanger 20 between the air taken through the air intake port and the exhaust gas.

Further, one end of the air supply passage 7 is connected to the heat exchanger 20. The other end of the air supply passage 7 is connected to the exhaust passage 2 between the engine 1 and the fuel adding injector 26. The air supply passage 7 includes at its midway an air pump 27 for discharging the air under a predetermined pressure from the side of the heat exchanger 20 towards the exhaust passage 2 at the upstream of the SOFC 3.

With the above-described construction, the air with its temperature raised in the heat exchanger 20 is introduced into the exhaust passage 2 at the upstream side of the SOFC 3 through the air supply passage 7. Consequently, the wall surface temperature of the exhaust passage 2 and the temperature of the exhaust gas can be raised. Thus, evaporation of the fuel added from the fuel adding injector 26 can be advanced.

Further, in the low-load region, a degree of raising the temperature of the wall surface of the exhaust passage 2 with the heat of the exhaust gas from the engine 1 is small, thereby the fuel added from the fuel adding injector 26 is liable to adhere to the wall surface of the exhaust passage 2. However, with the above-described construction, the temperature of the wall surface of the exhaust passage 2 and of the exhaust gas can be raised, thereby evaporation of the fuel adhered to the wall surface can be advanced. Consequently, even at the time of low-load operation, the power generation fuel can be supplied

stably to the SOFC 3.

Note that, in this embodiment, the other end of the air supply passage 7 may be connected to the exhaust passage 2 at more downstream from the fuel adding injector 26. Specifically, it is sufficient to raise the temperature of a location in the exhaust passage 2 where the fuel is adhered, by supplying the air from the air supply passage 7.

With this embodiment, the fuel adding injector 26 constitutes the fuel supply system of the present invention.